CALIFORNIA
ENERGY
COMMISSION

Residential Electric Power Security Project

CONSULTANT REPORT

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the "Residential Electric Power Security" project, Contract Number: 500-97-047, conducted by XANTREX Technology Incorporated, 3547-C South Higuera Street, San Luis Obispo, CA 93401. The report is entitled "Residential Electric Power Security Project." This project contributes to the Renewable Energy program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

The placement of Photovoltaic (PV) electric generation equipment on residential rooftops has been recognized as an important source of clean distributed energy for California. The utilization of this generation source has the additional benefit of simultaneously avoiding the cost of upgrading or building expensive new distribution lines at the local level.

Project Objectives

The overall goal of this program has been to raise California's PV system production and installation capacity by reducing complexity and enhancing performance, thus increasing availability and consumer benefit. Under this program, Kyocera Solar, Inc. and Xantrex Technology Inc. designed, assembled, and tested a new photovoltaic (PV) power system for residential rooftops.

<u>Technical Objective</u>

- Achieve a conversion efficiency for the power unit, operating at the higher voltage from the energy storage unit, of greater than 94 percent at 100 percent of rated output power.
- Achieve a total harmonic distortion below five percent.

<u>Economic Objectives</u>

- Reduce the material and direct labor cost of producing the Power Unit from $0.67 to $0.34 per Watt.
- Reduce the material and direct labor cost of installing the PV array from $7.00 to as low as $3.79 per square foot.

Project Approach

The cost of a photovoltaic generation system may be divided into two categories: PV module cost and balance-of-system (BOS) cost. This project addresses a way to reduce the BOS cost by:

- Standardizing the design
- Simplifying the design of the system and the power unit
- Improving the power conversion efficiency of the system
- Reducing on-site installation labor
- Increasing production volume

Xantrex Technology Inc. and Kyocera Solar, Inc. performed the work on this project to create a residential rooftop generation system requiring less engineering for site-specific applications and less time to install. The system also provides on-site energy storage for critical load operation during utility line service interruption while costing less than the equivalent custom PV systems that are commercially available.

Outcomes

Xantrex Technology Inc. and Kyocera Solar, Inc. completed the design, fabrication, and testing on the first higher voltage, modular, maintenance free, battery-based, residential electric power security system for PV applications of grid support, off-grid support, and backup power.

Technical Outcome

- Efficiency of power unit increased to 96 percent at power levels of 30 percent to 100 percent of rated output power.
- Total harmonic distortion was reduced to 0.9 percent at full rated load.

Economic Outcomes

Established economic goals were met:

- The material and direct labor cost of producing the Power Unit has been reduced from $0.67 for similar models, to $0.34 per Watt.
- The material and direct labor cost of installing the PV array has been reduced from $7.00 to as low as $3.79 per square foot.

This program has advanced California's PV system production and installation capacity and set the stage for future development of even more commercially available PV power systems:

- Over 80 residential rooftops have been equipped with the modular PV rooftop array designs and installation processes.
- A power unit with exceptionally high efficiency and low distortion was developed.
- A PV system with battery backup power during utility line outages was presented. This system will provide back-up power to the residential customer in times of utility grid interruption.

Conclusions

The Model 5000, Power Unit and the Model 6000, Energy Storage Unit are being evaluated for manufacturing per the Xantrex Product Creation and Support (PC&S) process. These two products must fit into existing Xantrex product technology platforms, replace an older product line, or initiate a new product platform.

Since this development contract start date, the residential backup power market and the distributed energy markets have changed significantly. The way product is manufactured at Xantrex Technology has also changed. When the Model 5000 and 6000 are brought into production, there will more than likely be some changes dictated by current market conditions.

Going forward, there already exists a credible scenario for next generation products. There is a mandate within the Xantrex organization to design all new products by using a small number of functional hardware and software modules. The next generation Model 5000, Power Unit, for example, would consist of three functional blocks that are used in other products as well; two half bridge modules, one DC to DC max power tracker and one remote display.

The advantages of this design philosophy are improved product reliability, lower product costs and easier application of mass production manufacturing techniques.

Benefits to California

Benefits to California include increased employment and reduced pollution.

- The average residential rooftop PV power system installed in Sacramento, California will produce 2,890 kWh of electricity per year, and eliminate 3,583 pounds of CO_2 and one pound of NOX emissions in the first year.
- The products designed under this contract are built in California and installed by California contractors.

Recommendation

- Extend PV design development to create a new product line, incorporating the optimized modular PV rooftop array design and installation process into kits for retail purchase.
- Increase efficiency of PV rooftop array while reducing production and installation costs.

Abstract

The overall goal of this program has been to increase California's PV system production and installation capacity. To reach this goal, Kyocera Solar, Inc. and Xantrex Technology Inc. have designed, assembled, and tested a new photovoltaic (PV) power system for residential rooftops. This system will offer to the consumer the installation of grid support rooftop PV systems at a reduced cost, as well as the option of battery backup for their residential power.

A new PV array system has been developed, which is pre-fabricated in a factory and installed on the residential rooftop using standard metal parts. This PV array design and installation process is suitable to be adapted to a new product line of PV installation kits for retail purchase.

To complement this new PV array, a modular, maintenance free, battery-based, Power Unit and Energy Storage Unit have been developed. Together, these components comprise a system that will enable the residential grid-tied customer to have the added benefit of back-up power. The design, fabrication, and testing have been completed for two prototypes of this system. These products have been evaluated for their structural integrity, electrical performance, reliability, cost, and manufacturability.

- At the time of this writing, over 80 systems utilizing the new PV array have been built and installed on rooftops in the greater Sacramento metropolitan area.
- The direct material and labor cost of the array installation has been reduced from a previous average cost of $7.00 per square foot, to as low as $3.79 per square foot.
- The Power Unit has raised the power conversion efficiency from 90 to 94 percent typical of similar models to 96 percent.
- The direct material and labor cost of the Power Unit has been reduced from $0.67 per watt in similar units, to $0.34 per watt.

1.0 Introduction

Solar power installations for residential rooftops have several drawbacks which limit their appeal to consumers and have thus restricted their application.

- The initial investment cost is very high.
- Custom system design and engineering is required for each installation.
- System inefficiency reduces actual power output.
- On-site storage is seldom made available in grid-support applications.

These obstacles must be overcome before residential rooftop PV generation may be fully developed as a renewable energy technology for on-site electrical generation and storage.

This report shows how the work performed by Xantrex Technology Inc. and Kyocera Solar, Inc. has addressed these obstacles, and how the volume of residential rooftop generation has been increased. Also discussed is what future steps may be taken to further enhance the goal of improving the reliability and quality of California's electricity by increasing the capacity of residential rooftop PV electricity generation.

Xantrex Technology Inc. and Kyocera Solar, Inc. together manufacture, sell, and install equipment for PV electricity generation. These companies share the goal of enhancing the growth of the residential PV market.

There are a great many potential customers for this equipment. The majority of these have opted to delay or discontinue their interest of investing in a residential rooftop PV generation system. The initial investment cost is prohibitive for many. For others, the complexity of engineering and design of the system for their application is daunting. Of the remaining potential customers, some are discouraged to learn that they will have no enhanced continuity of service because utility-interactive PV systems do not operate when the utility line service is interrupted.

Xantrex Technology Inc. and Kyocera Solar, Inc. performed the work on this project to create a residential rooftop generation system which requires less engineering for site-specific applications and less time to install, and which also provides the option of on-site energy storage for operation of critical loads during utility line service interruption while costing less than the equivalent custom PV systems that were available previously.

1.1. Summary of Actual Expenditures

This project has been funded by Xantrex Technology with support by NREL and PIER (Table 1).

Table 1. Summary of Expenditures

NREL	$974,218
PIER	$426,343
Xantrex	$250,000

1.2. Background

1.2.1. Technology Concept

Kyocera Solar, Inc. developed a method of panelizing and pre-wiring PV modules as a factory assembled unit. The panels are then mounted on the residential roof by use of a set of standardized mounting rails manufactured from commercially available steel shapes. The cost to install this system is lower than that of a typical custom-designed, built-in-place residential rooftop PV system.

Xantrex Technology Inc. completed the design and testing of a Power Unit and an Energy Storage Unit for residential off-grid and back-up power applications. This equipment will convert and condition the energy form the PV power source to make it available to the utility grid during normal grid operation. The energy storage capability will allow the residential rooftop PV generation system to continue supplying the household with high-quality electrical power during utility power interruptions.

In all PV systems, some power is lost or dissipated during the necessary conversions from the PV to the AC line. This is measured as efficiency; the higher the efficiency, the lower the power losses. Additionally, there is some distortion in the AC output due to the conversion process. This is measured as Total Harmonic Distortion (THD); the lower the THD, the better the performance. The power unit and energy storage units have been designed to have the highest efficiency and the lowest THD commercially available.

The system performance has been enhanced by the use of a higher voltage energy storage system. Common backup battery supply voltages are limited to 48 Volts DC. The Xantrex solution enables the use of supply battery voltages of 450 Volts DC. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the voltage boost stage required with low voltage storage systems. Additionally, the higher voltage energy storage source (batteries) provides for excellent transient response during sudden output load changes.

1.3. Project Objectives

1.3.1. Technical Performance Objectives

The power unit and energy storage unit (ESU) was built and tested, meeting the technical goals set forth. The feasibility of such a system has been demonstrated. Unlike other PV systems which use a collection of discrete battery chargers, inverters, relays and switches, the power unit is designed to perform all of these functions within a single enclosure containing bi-directional power circuitry and a common control module. Likewise, the ESU further eliminates the need for a complex site-specific system design coordinating batteries and a battery housing with the electrical equipment.

The goal for the power unit, operating at the higher voltage from the energy storage unit, was to achieve a conversion efficiency of greater than 94 percent at 100 percent of rated output power, with total harmonic distortion below five percent. The power unit design exceeded this goal by achieving 96 percent efficiency at power levels of 30 percent to 100 percent of rated output power. Total harmonic distortion remains under two percent throughout this range

1.3.2. Economic Performance Objectives

Achievement of the overall goal of this program - to increase California's PV system production and installation capacity - is affected by the economic reality that the price of PV systems is prohibitive to many individuals and organizations who might otherwise desire to have such systems installed. Therefore, this program addresses the cost of this new PV system with specific goals.

- PV Array Installation Costs--The material and direct labor cost of installing the PV array has been reduced from $7.00 to as low as $3.79 per square foot.
- Power Unit Production Costs--The material and direct labor cost of producing the Power Unit has been reduced from $0.67 to $0.34 per Watt.

1.4. Project Approach

This program has been organized into eight tasks involving the three elements of the design. Goals and objectives have been laid out in order to monitor and evaluate the results of the program.

1.4.1. Task 2.1 – PV Array Development

Under this task, the development of a new, modular structural interface between the PV array and the roof, and the electrical connection between PV modules was completed. A modular system with custom manufactured metal framing members was devised to reduce the installation complexity of the PV system. Two such systems were deployed.

The structural interface was then refined under T*ask 2.4, PV Array Optimization*, in order to meet the final cost goal of $4.50 per square foot for the direct materials and installation labor of the PV array.

1.4.2. Task 2.2 – Power Unit Development

A design blueprint was developed for a highly reliable power unit which would deliver up to 12kW of low distortion power divided equally into each phase of a 120/240 Volt split-phase residential power system. Efficiency was predicted to be above 95 percent over a wide power range, so that more of the energy generated by the PV would be used. This power unit was designed with an option to operate in conjunction with an energy storage unit, for household back-up power in the case of utility grid interruption.

1.4.3. Task 2.3 – Energy Storage Unit Development

A design blueprint for an energy storage unit was developed, for use with the power unit. Rather than the system designer or homeowner having to buy and house batteries, and design a custom system, the energy storage unit was planned with integral batteries, control electronics, and communication with the power unit.

1.4.4. Task 2.4 – PV Array Optimization

The objective of this task was to develop the final design and to demonstrate a modular, UL-listed residential PV Array with a direct materials and labor cost (exclusive of PV module cost) below $4.00 per square foot. After the successful implementation of the prototype arrays, the design was optimized to utilize standard metal shapes and reduce parts count while maintaining the time-savings and simplicity of the prototype modular design. The cost to install this optimized array is as low as $3.79 per square foot.

1.4.5. Task 2.5 – Power Unit Optimization

From the design blueprint, two power unit prototypes were produced and tested. The innovative packaging of the power unit was designed for outdoor deployment, ease of installation, and for user safety. Testing of the prototype power unit demonstrated the efficiency to be greater than 96 percent with a total harmonic distortion (THD) of only 0.9 percent, operating at a power level of 6.2 Kilowatts per AC line.

1.4.6. Task 2.6 – Energy Storage Unit Optimization

The design, testing and UL listing were completed for the first higher voltage, modular, maintenance free, battery-based, energy storage unit (ESU) for residential off-grid and backup power applications.

1.4.7. Task 2.7 – Operating Manual

A consumer-oriented installation manual has been created for the new PV system. This manual is available in Appendix I.

1.4.8. Task 2.8 – Production Readiness Plan

It is anticipated that the developments of the power unit and the energy storage unit will be extended to commercial product designs which will be made available to the consumer. An implementation plan to ramp up to full production has been created, to be used as a basis for future development.

2.0 Discussion

2.1. Task 2.1 – PV Array Development

The development of a structural interface between the PV array and the roof, and the electrical connection between PV modules was completed. Initially, a system with custom manufactured metal framing members was devised to reduce the installation complexity of the PV system. Two such systems were deployed.

The goal of this initial deployment was to demonstrate the effectiveness of a modular, pre-manufactured PV array in reducing the time required for design and installation of a rooftop PV system.

After the successful development and installation of tow prototypes of the modular PV array system, the design was optimized to achieve the desired cost goals.

The first prototype PV array installation (Figure 1) was based on the UPG/KSI patent #6,065,255. This array encompassed approximately 90 percent custom fabricated galvanized sheet and stainless steel materials. The goal of this type of design was to off set the cost of fabricated materials with volume of fabrication and simplicity of assembly, thus reducing the cost of field labor for the array installation process.

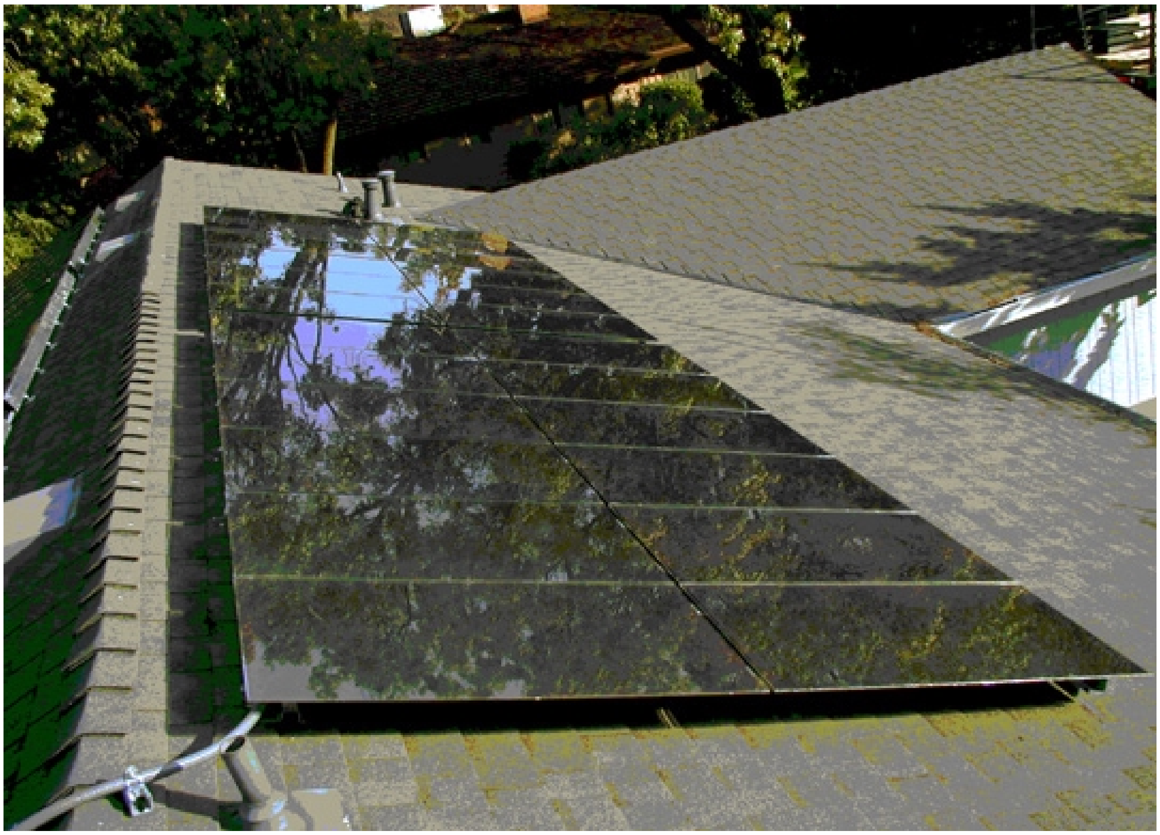

Figure 1. First Prototype Array

The PV panels were assembled within a factory environment. A two-module panel configuration was designed to minimize the cost of assembly labor and handling. During the PV panel assembly process, modules could be configured with parallel or series wiring to accommodate high or low voltages for different inverter applications. The two-module panel configuration was integral for the overall strength and stability of the support structure (Figure 2). Note the incorporation of the array wiring into the support structure.

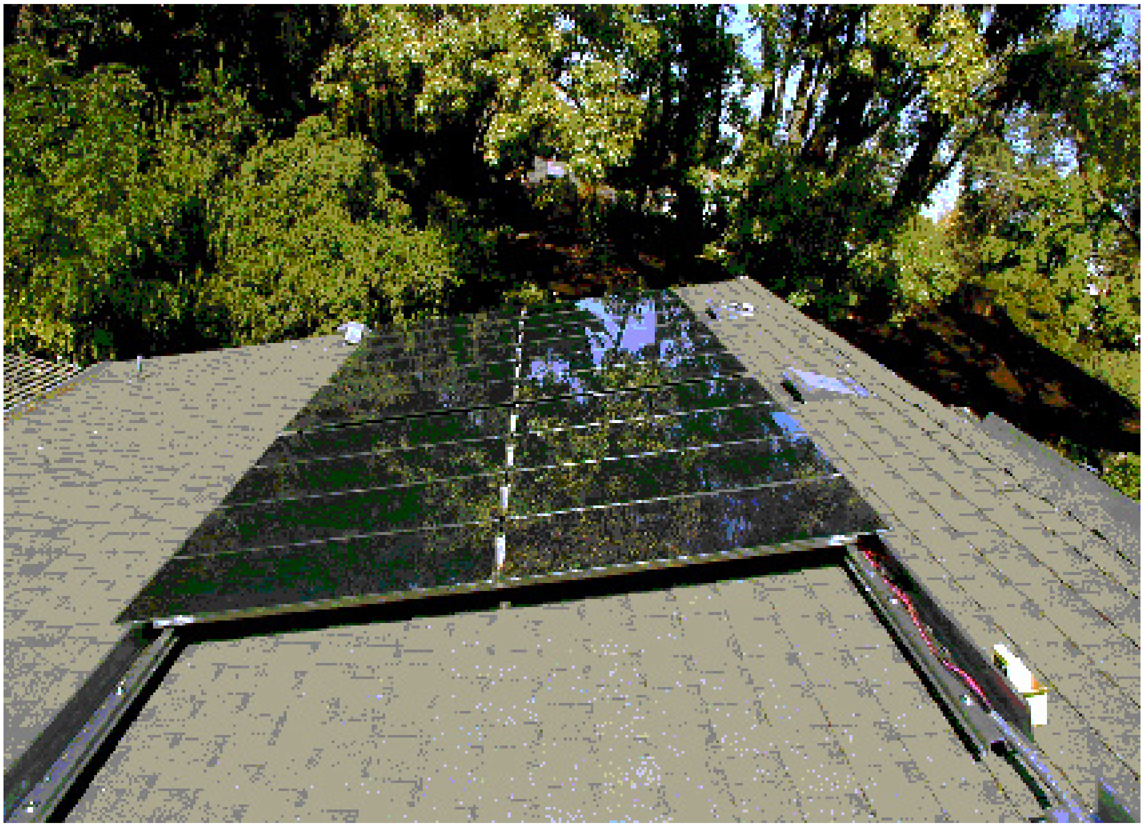

Figure 2. First Prototype Array, Partly Assembled

2.2. Task 2.4 – PV Array Optimization

The prototype array design demonstrated how the pre-fabricated PV array can simplify site-specific design and installation time for a rooftop PV system. The installation cost, however, was $11.76 per square foot, because of the cost of the custom fabricated materials used.

The cost goal for this program was $4.00 to $5.00 per square foot for the PV array installation materials and labor (excluding the PV panels). Quotations for material for 500 systems reduced the cost to approximately $8.50 per square foot. To achieve the cost goals, material cost was reduced by incorporating commercially available strut channel runners in place of the custom fabricated ones.

The runners now are placed vertically on top of the roof surface and rafters (Figure 3). This design eliminates the stand-off assemblies associated with horizontal structural mounting, which were required to permit water run off and avoid vegetation build up. A commercially available L-bracket is placed on the lower end of each runner to facilitate placement of the PV panels.

Figure 3. Final Design – Runners Attached to Roof

The PV panelization process was extended to incorporate up to four modules (thin film or crystalline), maintaining ease of assembly and handling, while enabling a greater degree of module array pre-wiring to be applied in the factory environment. This reduces the required number of runners and simplifies the field wiring requirements (Figure 4).

Figure 4. Final Design with Three PV Panels in Place

This entire PV array design now uses only two fabricated components. The modules are assembled into panels by attachment to a rail, which is fabricated from ASTM 653 Grade 50 structural steel. This rail is manufactured in a single operation, so that the cost of fabrication for the rail is only slightly more than that of purchasing a standard shape. Depending on the module configuration, either C-rails or Z-rails are used, in order to place the outer lip of the rail at the edge of the panel. A simple C-clamp assembly provides ease of PV panel placement and positional adjustment while maintaining maximum hold down strength to the strut channel runners.

This design has been finalized and is in production. Figure 5 shows the documentation for the fabrication and assembly of the PV panel.

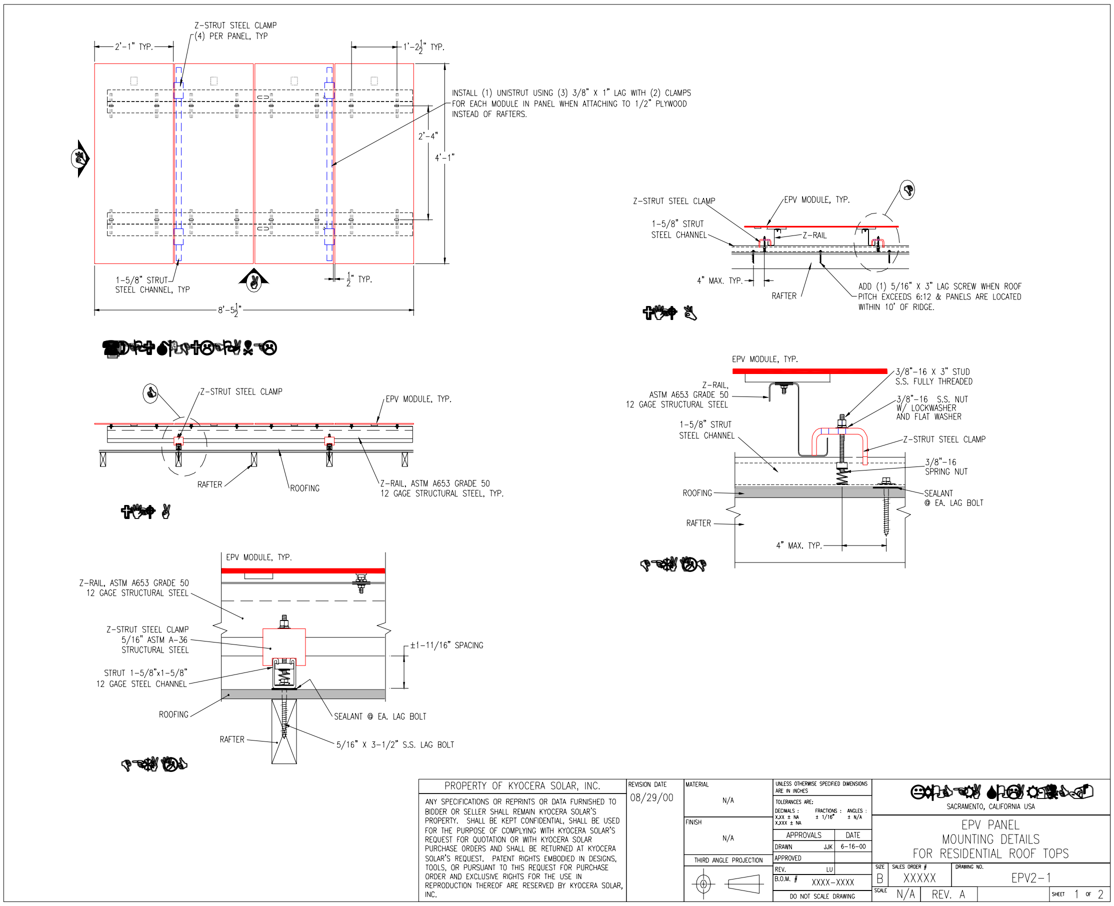

Figure 5. Engineering Documentation of PV Panel

The installation cost for the PV array has been substantially reduced with this design. Under the most favorable conditions, typically a single story dwelling with no roof obstructions and the electrical grid tie-in located on the wall under the roof top PV array, the cost of installation material and labor, excluding the PV modules, has been documented to be as low as $3.79 per square foot. More complex installations, such as two-story dwellings, and multiple roof angles, have had installation costs of $4.00 to $6.00 per square foot.

This system has been adapted to three different commercially available PV modules:

- Kyocera Solar Model KC120
- Siemens Solar Model SP-75
- EPV Model EPV40

2.3. Tasks 2.2 and 2.5 – Power Unit Development and Optimization

A design was developed for a highly reliable power unit which would deliver up to 12kW of low distortion power divided equally into each phase of a 120/240 Volt split-phase residential power system. Efficiency was predicted to be above 95 percent over a wide power range, so that more of the energy generated by the PV would be utilized. This power unit was designed with an option to operate in conjunction with an energy storage unit, for household back-up power in the case of utility grid interruption.

Two Power Unit prototypes were produced and tested. The innovative packaging of the Power Unit was designed for outdoor deployment, ease of installation, and for user safety. The Power Unit performs all of the following functions:

- Battery charging from the PV array.
- Battery charging from the utility.
- Grid-support AC output.
- Stand-alone backup AC output.
- Automatic utility disconnect.

2.3.1. Theory of Operation

The power unit (Figure 6) uses a higher voltage battery interface and PV interface. The higher voltage battery interface allows the use of a higher voltage energy storage unit for increased efficiency and improved load response. The wide-range PV interface voltage accommodates a large variety of PV module arrangements, and accepts the reduced DC wiring and combination that results from the use of the prefabricated high voltage PV array.

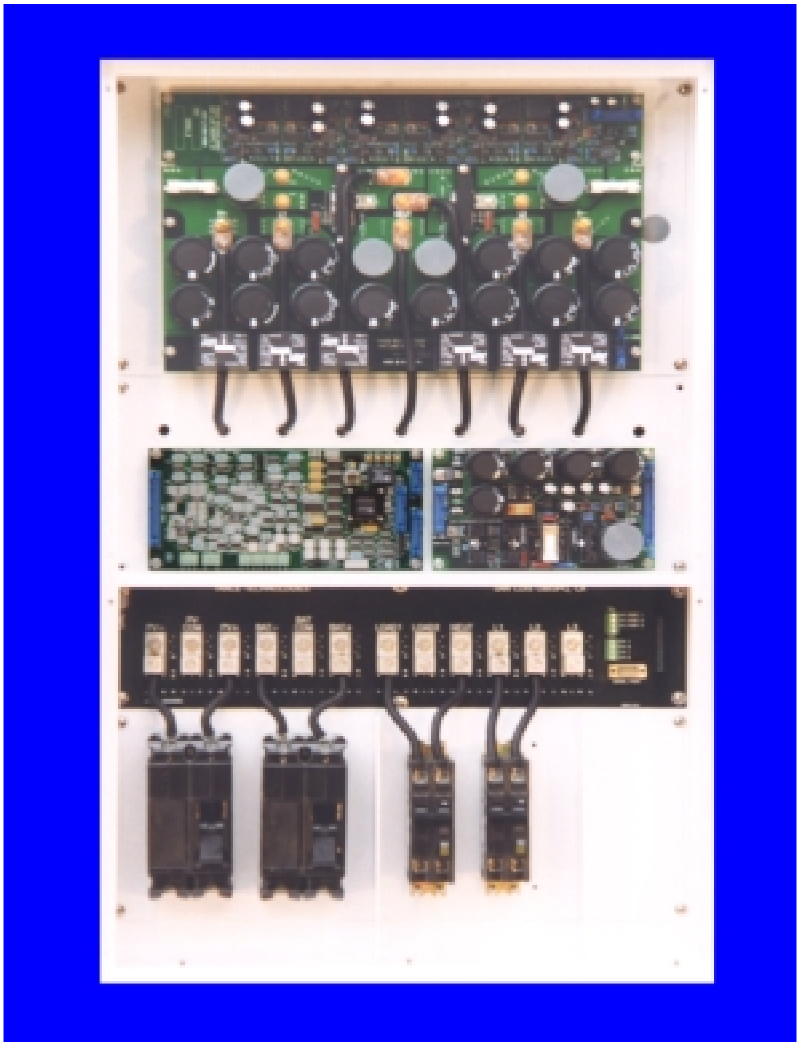

Figure 6. Power Unit with Front Panel Removed

Rather than storing energy at a low voltage and then boosting the full output power during stand alone or backup operation, this unit boosts the PV voltage as the PV power enters the power unit, and energy is stored at the higher voltage. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the full power voltage boost stage required with low voltage storage systems. Also, higher DC input voltage means proportionately lower input currents. Lower input currents translate to lower copper losses, lower semiconductor conduction losses and smaller wire and terminal sizes. Additionally, from a dynamic performance perspective, having the energy storage source (batteries) directly across the DC bus provides for excellent transient response during sudden output load changes.

2.3.2. Residential Power Unit Features

- Stand alone or grid tied operation
- 12kW continuous / 19.2kW peak power
- High conversion efficiency >96 percent @ full load
- Single enclosure system integrated design:
  - AC Line and Load Breakers
  - Auto Transfer Contactor
  - PV Max Power Tracker
  - Split Phase Inverter
- Weatherproof, tamperproof enclosure
- Two independently regulated 120Vac outputs
- Configurable as 120V @ ”200A” or 240V @ “100A”
- Low noise fan with continuously variable speed control
- Remote display showing hours of battery capacity remaining at current usage rate.
- Designed for use with the Xantrex Energy Storage Unit

Xantrex Technology Inc., has completed the design and testing of a power unit for residential off-grid and back-up power applications. A new, consolidated power unit which performs all of the functions necessary for a versatile, integrated standalone and residential backup power supply was shown to be commercially viable. The innovative packaging of the power unit was designed for outdoor deployment, ease of installation and for user safety.

2.3.3. Power Unit Performance

The power unit has been subjected to a series of performance tests. These tests have simulated typical use of this equipment for PV applications. The prototypes have been evaluated for their structural integrity, electrical performance, reliability, cost, and manufacturability.

- Testing of the prototype Power Unit demonstrated total harmonic distortion (THD) to be only 0.9 percent, operating at a power level of 6.2 Kilowatts per AC line (Figure 7, Figure 8 and Figure 10).

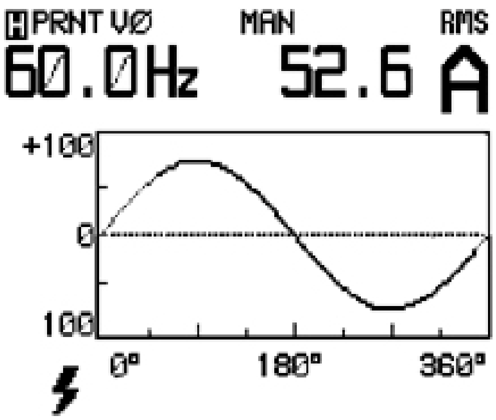

Figure 7. Power Unit Current Waveform

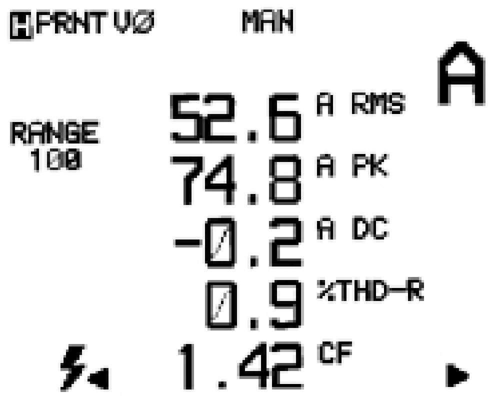

Figure 8. Power Unit Current Data

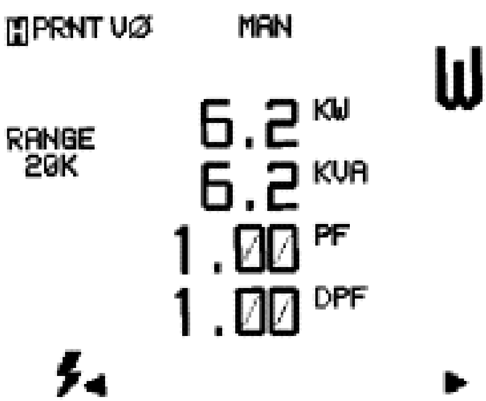

Figure 9. Output Power per Line

- A power conversion efficiency of 96 percent has been achieved, at power levels of 30 percent to 100 percent of rated output power (Figure 10).

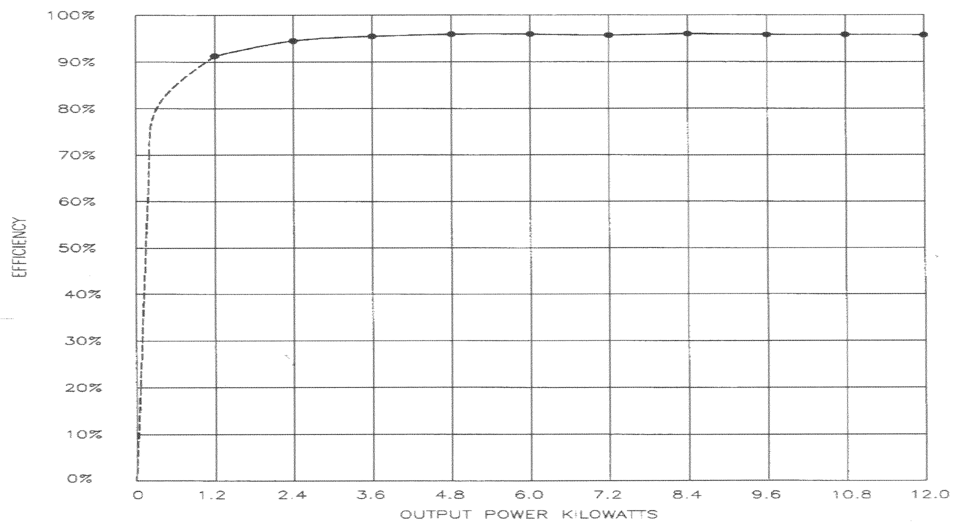

Figure 10. Power Unit Efficiency

- Total harmonic distortion remains under two percent throughout this range.

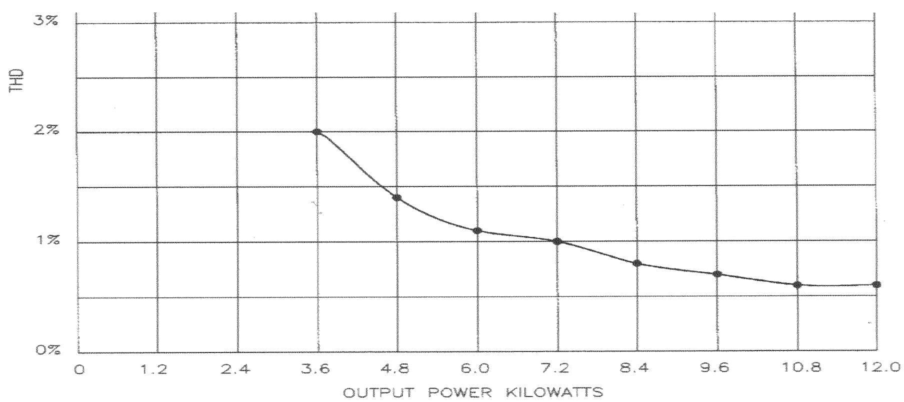

Figure 11. Power Unit Distortion

2.4. Tasks 2.3 and 2.6 – Energy Storage Unit Development and Optimization

Xantrex Technology Inc. has completed the design, testing and UL listing on an energy storage unit (ESU).

A design for an energy storage unit was first developed, for use with the power unit. Rather than the leaving the system designer or homeowner to buy and house batteries and design a custom system, the energy storage unit was planned with integral batteries, control electronics, and communication with the power unit.

A complete design was then created for the ESU and two prototypes were manufactured. The innovative packaging of the ESU was designed for outdoor deployment, ease of transportation, ease of installation, and for user safety. The ESU also employs a smart temperature regulation scheme which uses the thermal mass of the batteries in conjunction with the tailored heat transfer characteristics of the enclosure to regulate the battery cell temperatures for optimum battery lifetime.

2.4.1. Theory of Operation

Common backup battery supply voltages are limited to 48 Volts DC. The Xantrex solution enables the use of supply battery voltages of 450 Volts DC. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the voltage "boost" stage required with low voltage storage systems. Also, higher DC input voltage means proportionately lower input currents. Lower input currents translate to lower copper losses, lower semiconductor conduction losses and smaller wire and terminal sizes. Additionally, from a dynamic performance perspective, having the energy storage source (batteries) directly across the DC bus provides for excellent transient response during sudden output load changes.

Traditionally, series strings of batteries had severely compromised lifetimes and low recharge energy capacity. These technical difficulties were overcome and this higher voltage series battery string topology was made commercially viable through the development of an innovative, low cost, microprocessor-based Active Charge Control circuit. This smart circuit actively balances the charge of all the individual battery components in the series string, maintaining the full battery recharge rate and lifetime.

2.4.2. Energy Storage Unit Features

- 13kW-hour energy storage capacity
- Maintenance free batteries
- Easy to parallel for added capacity
- Load break safety switch disconnect
- Low current, higher voltage design
- Weatherproof, tamperproof enclosure
- Insulated enclosure with smart temperature control
- Active overcharge protection

Figure 12. Energy Storage Unit with Top and Side Panels Removed

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2.4.3. Economic Analysis

The manufacturing and assembly costs of the Power Unit have been finalized. The cost is $4060.28 for a 12 kilowatt Power Unit, or $0.34 per watt.

Table 2. Power Unit Direct Material and Labor Cost

Qty	P/N	Title	Parts	Parts Cost	Labor	Parts + Labor
	A05000	Assembly, 12KW Inverter			$120.00	$120.00
1	B05100A	Assembly, PCB, Power Bridge Board	$534.68	$534.68	$60.00	$594.68
1	B05200A	Assembly, PCB, Contactor Board	$159.58	$159.58	$7.00	$166.58
1	B05300A	Assembly, PCB, PV Combiner Board	$106.45	$106.45	$12.00	$118.45
1	B05400A	Assembly, PCB, Capacitor Board	$42.45	$42.45	$4.00	$46.45
1	B05500B	Assembly, PCB, Control Board	$131.20	$131.20	$145.00	$276.20
1	B05550A	Assembly, PCB, Operator Int. Board	$19.94	$19.94	$9.00	$28.94
1	B05600A	Assembly, PCB, Crowbar Board	$146.31	$146.31	$42.00	$188.31
1	B05650A	Assembly, PCB, Power Supply Board	$171.12	$171.12	$30.00	$201.12
1	B05700A	Assembly, PCB, Drive Board	$146.46	$146.46	$32.00	$178.46
32	B1-1032012	Screw, Pan Head	$0.05	$1.57		$1.57
2	FAN-PQ24B4	Fan, 24 V dc	$48.00	$96.00		$96.00
1	FLTR-PF4550	Filter, air	$12.35	$12.35		$12.35
10	GR-34516	Grommet, Rubber	$0.27	$2.69		$2.69
2	IC-LM35CAZ	IC,Temperature Sensor	$10.00	$20.00		$20.00
1	J1-TA2	Lug, Box	$0.58	$0.58		$0.58
1	J2-1DB	Terminal Block	$32.90	$32.90		$32.90
1	J2-1SB	Terminal Block	$5.86	$5.86		$5.86
6	J4-IDC20	Connector, IDC	$1.28	$7.69		$7.69
6	J4-IDC40	Connector, IDC	$1.97	$11.84		$11.84
1	K5-192DC60A-S	Breaker	$250.55	$250.55		$250.55
1	K5-QOU2100	Breaker	$40.00	$40.00		$40.00
1	M05001A	Enclosure	$400.00	$400.00		$400.00
1	M05002A	Enclosure Door	$0.00	$0.00		$0.00
3	M05003A	Barrier	$17.97	$53.91		$53.91
4	M05004A	Transformer Mounting Cup, Small	$0.00	$0.00		$0.00
4	M05005A	Transformer Mounting Cup, Large	$0.00	$0.00		$0.00
1	M05006A	Heatsink	$60.83	$60.83	$37.00	$97.83
1	M05007A	Panel, Magnetics Access	$249.91	$249.91		$249.91
1	M05008A	Panel, Heatsink Access	$49.00	$49.00		$49.00
1	M05009A	Panel, Bottom Access	$56.74	$56.74		$56.74
1	M05010A	Panel, Top Access	$60.53	$60.53		$60.53
1	M05011A	Bracket, Capacitor Assembly	$63.00	$63.00		$63.00
2	M05012A	Hood	$45.90	$91.80		$91.80
1	M05013A	Filter Screen Assembly	$0.00	$0.00		$0.00
32	N1-1032NI	Nut, Nylon Insert	$0.06	$1.98		$1.98
4	SO3-FF103204375GA	Standoff	$0.39	$1.56		$1.56
4	SO3-FF1032075GA	Standoff	$0.52	$2.08		$2.08
4	SO3-MF1032012GA	Standoff	$2.05	$8.20		$8.20
4	SO3-MF1032100GA	Standoff	$0.02	$0.06		$0.06
4	SO4-FF08320875IGA	Standoff	$0.91	$3.64		$3.64
4	SO4-FF10321625IGA	Standoff	$1.50	$6.00		$6.00
10	WR1-6HYP	Wire, single conductor	$0.05	$0.53		$0.53
5	WR4-20GRY	Cable, Flat ribbon	$0.15	$0.73		$0.73
5	WR4-40GRY	Cable, Flat ribbon	$0.31	$1.55		$1.55
2	X05090	Inductor, Primary Line Filter	$120.00	$240.00		$240.00
2	X05091	Inductor, Line Filter, Secondary	$60.00	$120.00		$120.00
2	X05092	Balun	$50.00	$100.00		$100.00
2	X05093	Boost Inductor	$25.00	$50.00		$50.00
		Total Parts		$3,562.28		
		Total Labor			$498.00	
		Total Parts and Labor for 1 unit				$4,060.28

An objective of this project was to develop the final design and to demonstrate a modular, UL-listed residential PV Array with a direct materials and labor cost (exclusive of PV module cost) below $4.00 per square foot. The system that has been developed and demonstrated has a cost as low as $3.79 to $3.95 per square foot for installations with minimum complexity.

Table 3. Installation Cost, Exclusive of Module Cost

MODULE TYPE	AREA OF MODULE	NUMBER OF MODULES	TOTAL AREA OF MODULES	TOTAL COST	NON-ARRAY COSTS	ARRAY COST	ARRAY COST PER SQU. FOOT
EPV40	8.51	60	511	2148	214.8	1933.20	3.79
EPV40	8.51	100	851	3733	373.3	3359.70	3.95

3.0 Outcomes

Xantrex Technology Inc. and Kyocera Solar, Inc have completed design, testing, and UL listing phases on the first higher voltage, modular, maintenance free, battery-based, residential electric power security system for photovoltaic applications of grid support, off-grid, and backup power. These products have been evaluated by Xantrex Technology Inc. and Kyocera Solar, Inc. for their structural integrity, electrical performance, reliability, cost, and manufacturability.

This program has advanced California's PV system production and installation capacity and set the stage for future development of even more commercially available PV power systems:

- Over 80 residential rooftops have been equipped with the modular PV rooftop array designs and installation processes.
- A power unit with exceptionally high efficiency and low distortion was developed.
- A PV system with battery backup power during utility line outages was presented. This system will provide back-up power to the residential customer in times of utility grid interruption.

3.1. Technical Performance Outcomes

The power unit and energy storage unit (ESU) was built and tested, meeting the technical goals set forth. The feasibility of such a system has been demonstrated. Unlike other PV systems which use a collection of discrete battery chargers, inverters, relays and switches, the power unit is designed to perform all of these functions within a single enclosure containing bi-directional power circuitry and a common control module. Likewise, the ESU further eliminates the need for a complex site-specific system design coordinating batteries and a battery housing with the electrical equipment.

The goal for the power unit, operating at the higher voltage from the energy storage unit, was to achieve a conversion efficiency of greater than 94 percent at 100 percent of rated output power, with total harmonic distortion below five percent. The power unit design has exceeded this goal by achieving 96 percent efficiency at power levels of 30 percent to 100 percent of rated output power. Total harmonic distortion remains under two percent throughout this range

3.2. Economic Performance Outcomes

Achievement of the overall goal of this program - to increase California's PV system production and installation capacity - is affected by the economic reality that the price of PV systems is prohibitive to many individuals and organizations who might otherwise desire to have such systems installed. Therefore, this program addresses the cost of this new PV system with specific goals.

- PV Array Installation Costs--The material and direct labor cost of installing the PV array has been reduced from $7.00 to as low as $3.79 per square foot.
- Power Unit Production Costs--The material and direct labor cost of producing the Power Unit has been reduced from $0.67 to $0.34 per Watt.

4.0 Conclusions and Recommendations

4.1. Conclusions

The Model 5000, Power Unit and the Model 6000, Energy Storage Unit are now being evaluated for manufacturing per the Xantrex Product Creation and Support (PC&S) process. These two products must fit into existing Xantrex product technology platforms, replace an older product line or initiate a new product platform.

Since this development contract start date, the residential backup power market and the distributed energy markets have changed significantly. The way product is manufactured at Xantrex Technology has also changed. When the Model 5000 and 6000 are brought into production, there will more than likely be some changes dictated by current market conditions.

Going forward, there already exists a credible scenario for next generation products. There is a mandate within the Xantrex organization to design all new products by using a small number of functional hardware and software modules. The next generation Model 5000, Power Unit, for example, would consist of three functional blocks that are used in other products as well; two half bridge modules, one DC to DC max power tracker and one remote display.

The advantages of this design philosophy are improved product reliability, lower product costs and easier application of mass production manufacturing techniques.

4.2. Benefits to California

The benefits to California include increased employment and reduced pollution.

- The average residential rooftop PV power system installed in Sacramento, California will produce 2,890 kWh of electricity per year, and eliminate 3,583 pounds of CO_2 and one pound of NOX emissions in the first year.
- The products designed under this contract are built in California and installed by California contractors.

Xantrex Technology Inc in Livermore, CA occupies approximately 10,000 square feet of light industrial space. The facilities include manufacturing assembly and test, an engineering development laboratory, and engineering and administrative office space.

The Utility Power Group (UPG) division of Kyocera Solar, Inc. is based in Sacramento, California. UPG provides Solar photovoltaic power systems to government, industrial, commercial and residential customers that desire a source of pollution-free and reliable electrical power. They are the largest integrator of grid systems in the U.S.

Together, these companies employ Californians while providing clean electricity for California.

4.3. Recommendation

Improve product reliability, lower product costs, and make application of mass production manufacturing techniques easier by designing new products using a small number of functional hardware and software modules. The next generation Model 5000, Power Unit, for example, would consist of three functional blocks that are used in other products as well.

5.0 Glossary

Efficiency	The ratio of useful output power to the input power delivered to a device. The higher the efficiency of an inverter, the less power is wasted.
Energy Storage Unit (ESU)	A system integrated component incorporating storage batteries with other system control and protection functions.
Grid-Support	A photovoltaic system that is connected to a centralized electrical power network. Also, Utility Interactive.
Photovoltaic (PV) Array	A group of photovoltaic modules wired together to produce a specific amount of power.
Photovoltaic (PV) Cell	A semi-conductor device that converts light directly into electricity.
Photovoltaic (PV) Module	A number of solar electric cells wired together to form a unit, or a thin-film solar cell, in a sealed frame of convenient size.
Power Unit	A system integrated component incorporating an inverter with other system control and protection functions.
System Integrated	Used to describe a component which combines the functions of several commonly separate devices, into one component.
Total Harmonic Distortion	The ratio of a wave's harmonic content to its fundamental component, expressed as a percentage. It is a measure of the extent to which a waveform is distorted by harmonic content. It is usually expressed as current or voltage "total harmonic distortion" or “THD”.

Appenidix I
Installation Manual